606

CHANGES IN SPECIFIC GRAVITY, STARCH CONTENT, AND SLOUGHING OF POTATOES DURING STORAGE

R .T. WHITTENBERGER

Eastern Regional Research Laboratory[1], *Philadelphia 18, Pa.*

The value of the specific gravity method for predetermining the cooking or processing quality of potatoes cannot seriously be questioned. Numerous studies have shown that tubers of high specific gravity give a characteristically mealy product, whereas those of low specific gravity become watery or soggy when cooked. Furthermore, high density tubers give increased yields of chips (5), mashed potato powder, and other similar dehydrated products (1). The advantages of being able to measure and to separate high density tubers from those of low density is therefore readily apparent.

Although a general correlation between high specific gravity and mealiness has been noted, little attention has been given to possible imperfections in the relationship. It usually is assumed that a particular specific gravity rating indicates a special type of texture. It is possible, however, that tubers of the same density and variety may vary appreciably in their texture, or that the same tubers may change both in density and in texture during storage. Our data show that these variations do occur.

In our work on the texture of potatoes as indicated by their sloughing losses, we usually were able to separate tubers which would slough from those which would not, by differences in their specific gravity. Tubers of low specific gravity never sloughed, but the high density tubers exhibited a considerable variation in the degree of sloughing. The need for detailed information on the specific gravity-sloughing relationship, especially in the high specific gravity range, led to the present study. The study was concerned with the changes in a single lot of tubers which was divided and subjected to different storage conditions.

MATERIALS AND METHODS

Irish Cobblers, grown near Waterville, New York, in 1949, were divided by flotation in brine into three lots of specific gravity 1.085 and one lot of specific gravity 1.095. Tubers of low specific gravity were discarded. One lot of specific gravity 1.085 was stored at 75° F., a second lot at 50° F., and the third lot at 35° F. The relative humidities at the three temperatures were 53, 72, and 89 per cent, respectively. The lot of specific

[1] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture.

gravity 1.095 was stored at 50° F. At periodic intervals, previously weighed 20-tuber samples were removed from each lot for study and analysis.

Sloughing losses were measured in triplicate with tissue specimens of nearly uniform density cut from the tubers, in a manner described by Whittenberger and Nutting (9). Only 3 or 4 specimens (about 10 gms. each) of the same specific gravity could be cut from an average-size tuber. The specific gravity of each specimen was determined, after which specimens of the same density were pooled for the measurement of sloughing loss and starch content. Tissue specimens rather than whole tubers were used because the latter were not sufficiently homogeneous in specific gravity. A tuber of specific gravity 1.095, for example, ranges in specific gravity from about 1.120 in one region to 1.060 in another. In contrast, the tissue specimens were nearly uniform in density.

From the tubers of specific gravity 1.085, tissue specimens of specific gravity 1.075, 1.095, and 1.100 were selected for measurement of sloughing loss and starch content; from the tubers of specific gravity 1.095, specimens of specific gravity 1.075, 1.100 and 1.110 were selected. For the sake of brevity, however, only part of the data will be reported in this paper. In cases where the tubers changed in density, test specimens of the original densities were selected for study, except where otherwise noted.

The Steiner-Guthrie method (6) was used for the starch determinations, and total dry matter was measured by drying the samples in an air oven for 16 hours at 150° F. and then for 2 hours at 266° F.

Changes in Specific Gravity and Sloughing

There was no change in the specific gravity of tubers stored at 35° F. (Table 1). However, tubers stored at 50° F. slowly increased in specific gravity, the original sample of specific gravity 1.085 attaining a value of 1.094 after 24 weeks of storage. Likewise, the specific gravity of tubers held at 75° F. increased. The increase was more rapid than that of the sample stored at 50° F. A second sample stored at 75° F. for 8 weeks (not shown in table 1) increased in specific gravity from 1.085 to 1.093. Since this sample had been stored previously at 50° F. until the dormant period had passed, it is not comparable with that shown in table 1. Small tubers increased more rapidly than did the large ones. Our results are not completely comparable with those of Terman *et al.* (7), who found that potatoes stored at 36°, 40°, and 50° F. increased in specific gravity.

The increases in specific gravity were correlated with shrinkage of the tubers. For example, the weight losses, including sprouts, of the 35° and 50° F. samples at the end of 24 weeks of storage were 2 and 25 per cent, respectively. About one-half of the 25 per cent loss was due to sprouts and the remainder to loss of water vapor and carbon dioxide. The 75° F. sample (Table 1) decreased 8 per cent in weight in 8 weeks. Shrinkage was, of course, most pronounced after dormancy had been broken and the tubers had begun to sprout. There was but little shrinkage or change in specific gravity during dormancy.

Meanwhile, the extent of sloughing decreased in all samples during storage (Table 1). The most rapid decrease occurred in the tubers held at 35° F., whereas the least rapid change occurred in the samples stored at 50° F. The pH of the expressed juice of all samples remained relatively constant ,ranging from approximately 6.0 to 6.2.

TABLE 1.—*Changes in specific gravity and sloughing loss of potatoes during storage*

Temp. of Storage (F.)	Storage Period in Weeks: 0		8		16		24	
	Spec. Grav.[1]	Sloughing Loss, Per cent[2]	Spec. Grav.[1]	Sloughing Loss,[3] Per cent[2]	Spec. Grav.[1]	Sloughing Loss, Per cent[2]	Spec. Grav.[1]	Sloughing Loss, Per cent[2]
35°	1.085	14	1.085	1.0	1.085	1	1.085	0
50°	1.085	14	1.085	7.8	1.088	7	1.094	4.0[5]
50°	1.095	26	1.095	20.6	1.097	15	1.102	8
75°	1.085	14	1.087	3.6		—	—	—

[1] Whole tubers were used.
[2] Dry weight basis. Tissue specimens of specific gravity 1.100 were used except in the case of the second sample stored at 50° F. In that case, specimens of specific gravity 1.110 were used.
[3] The difference required for significance at the 5 per cent level among the samples of this column was 2.9 per cent.
[4] At 75° F., the tubers did not remain sound for 16 weeks.
[5] The sloughing loss from tissues of specific gravity 1.110 of this sample was 4.3 per cent.

SPECIFIC GRAVITY AND STARCH CONTENT

To further an understanding of the causes for the observed changes in texture, starch and dry matter determinations were made of the tubers and tissue specimens used in this study. It was possible that some of the changes in texture which were not correlated with changes in specific gravity might be correlated with changes in starch content. In other words, it was desirable to test the reliability of the specific gravity method for estimating starch content. Accordingly, in table 2, the results obtained by the specific gravity method of von Scheele *et al.* (4) are compared with those of a chemical method (6).

The data show that the specific gravity ratings satisfactorily indicated the starch content both of freshly-harvested potatoes and of those stored at 50° F. However, tubers which were stored at 75° F. and had lost considerable weight contained more starch than was indicated by the specific gravity method. One probable cause for this is the increased proportion of skin or cork in a shrunken tuber, particularly if the tuber is small. Since the cork contains air and is of low specific gravity, a compensating increase in specific gravity of internal tissues must occur if the tuber is to remain of the same density. The concentration of starch therefore was greater than was indicated by the specific gravity rating. Data on peeled tissues substantiated this explanation.

The most serious shortcoming of the specific gravity method for estimating starch is revealed by the data on cold-stored (35° F.) tubers. Always the true starch content was lower than was indicated by the specific gravity method. The probable reason for this was that some of the starch was converted to sugar, which is similar to starch in density.

The starch content of cold-stored tubers could be estimated rapidly, however, if the soluble solids content as well as the specific gravity were known. If the soluble solids content (estimated with the Abbe refractometer) was subtracted from the dry matter content (estimated from specific gravity measurements), a value was obtained which closely approximated the starch content. As an example, the dry matter content of tissues stored for 8 weeks at 35° F. was 22.8 per cent, fresh weight basis, and the soluble solids content was 9.7 per cent. The estimated starch content was therefore 13.1 per cent, which compared well with the value of 13.5 per cent obtained by chemical analysis. The amount of non-starch insoluble solids was small and was neglected in the present case.

The soluble solids fraction as estimated with the Abbe refractometer certainly contained appreciable quantities of soluble proteins, pectins, and mineral salts, as well as sugars. Because the scale of the refractometer was calibrated for sugars only, it was therefore necessary to apply a correction factor, or to recalibrate the scale. By gravimetric analysis, this factor was found to be about 0.93 for tubers stored at 35° F. In other words, the scale readings were multiplied by 0.93 for correction. The correction factor for tubers stored at 50° F. was 0.88.

The specific gravity method for estimating starch was almost equally applicable to unpeeled tubers and to peeled tissue specimens (Table 2). As noted previously, however, the adverse effect of a relatively high proportion of skin (storage at 75° F.) was minimized when peeled tissues were used. The tissues, of course, were not permitted to dry or to soak for even one minute either in water or in salt solution.

TABLE 2.—*Representative data comparing the specific gravity and chemical methods for determining the starch and dry matter content of Irish Cobbler potatoes stored under various conditions.*

Storage History	Specific Gravity	Starch, Per cent[1]		Dry Matter, Per cent[1]	
		Specific Gravity Method[2]	Chemical Method[3]	Specific Gravity Method[2]	By Oven Drying
Whole tubers					
Original	1.085	14.8	14.9	21.2	22.0
"	1.095	16.8	17.1	23.3	23.1
35° F. 8 weeks	1.085	14.8	12.4	21.2	21.6
" 16 "	1.085	14.8	11.1	21.2	21.3
50° F. 16 weeks	1.085	14.8	15.2	21.2	21.3
" " "	1.095	16.8	16.5	23.3	23.0
75° F. 8 weeks	1.085	14.8	16.8	21.2	23.4
" " "	1.100	17.8	19.6	24.4	28.2
Tissue pieces					
Original	1.075	12.8	12.1	19.1	18.9
"	1.110	19.8	20.4	26.5	27.2
35° F. 8 weeks	1.075	12.8	9.5	19.1	18.4
" " "	1.100	17.8	16.0	24.4	25.1
50° F. 8 weeks	1.075	12.8	12.2	19.1	18.0
" " "	1.100	17.8	18.6	24.4	24.8
75° F. 8 weeks	1.075	12.8	12.2	19.1	18.9
" " "	1.100	17.8	18.4	24.4	25.8

[1] Fresh weight basis.
[2] The graph of von Scheele *et al.* (4) was used for both whole tubers and tissue pieces.
[3] The method of Steiner and Guthrie (6) was used.

In general, the specific gravity data reliably indicated the dry matter content of the tubers, even of those stored at 35° F. (Table 2). Samples showing the greatest variation were those in which the skin cork had become the most concentrated (storage at 75° F.). The data fitted the curve of von Scheele *et al.* (4) better than they did the curve of Dunn and Nylund (2). Both the starch and dry matter data tended to be somewhat higher than that of von Scheele in the upper range, and somewhat lower in the lower range.

An interesting feature of the present study was the good correlation obtained between soluble solids content and specific gravity within the tissues of a single tuber. For example, tissue specimens of specific gravity 1.120, 1.110, 1.085, and 1.060 were cut from different regions of a tuber (specific gravity 1.095) stored at 50° F. for two weeks. The soluble solids contents of the specimens were 8.1, 7.5, 6.6, and 5.6 per cent, respectively. This may mean that the cells in the tuber which synthesize the most starch also contain the greatest concentrations of proteins, pectins, and mineral salts. The correlation held also when whole tubers varying in specific gravity were compared. The significance of the correlation and the possible effects of these materials upon texture are not clear.

Effects of Changing the Storage Temperature

The tubers used in obtaining the data of table 3 were stored successively at 50° F. for 2 weeks; at 35° F. for 16 weeks; and at 75° F. for 2 weeks. They showed almost no change in specific gravity during these periods. In contrast, they changed markedly in degree of sloughing and in starch content. At the low temperature their degree of sloughing and starch content decreased, but when the tubers were returned to warm (75° F.) storage, they increased both in sloughing and in starch content. A greater increase in sloughing was observed in a previous study (9). Meanwhile, the changes in soluble solids content were opposite to those of the starch. If the tubers were reconditioned at 75° F. for more than two weeks after cold storage, they showed a tendency to decrease in specific gravity.

Table 3.—*Effects on potatoes of a sequence of storage temperatures*

Factor Observed	Changes in Temperature and Duration of Storage		
	1. —> 50° F. 2 weeks	2. —> 35° F. 16 weeks	3. 75° F. 2 weeks
Specific gravity[1]	1.085	1.085	1.085
Sloughing loss[2]	5.5	0.8[4]	1.4[4]
Starch[3]	17.2	13.6	16.7
Soluble solids[3]	6.7	9.9	7.2
pH of fresh juice	6.0	6.1	6.4

[1] Whole tubers were used.
[2] Per cent, dry weight basis, of tissues of specific gravity 1.095.
[3] Per cent, fresh weight basis, of tissues of specific gravity 1.095.
[4] Significantly different at the 5 per cent level.

Discussion

The results shown in tables 1 and 3 point out certain limitations of the specific gravity grading method which to our knowledge are not mentioned in the current literature. (1) The relationship between specific gravity and sloughing is a changing one, and is dependent largely upon the physiological condition of the tubers. (2) Sloughing may decrease or increase with no change in specific gravity. (3) Sloughing may actually decrease as specific gravity increases, or, in a sense, there may be under certain conditions an inverse relationship between specific gravity and sloughing.

These observations appear to be at variance with the generally accepted concept concerning specific gravity and texture. It is possible, however, to reconcile our findings with those of previous investigators. Despite the quantitative differences in the relationship between specific gravity and sloughing among our samples, within any one sample the correlation between specific gravity and sloughing was excellent. To illustrate, sloughing losses from tissues of specific gravity 1.100, 1.095, and 1.075 were originally 14.4, 8.9, and 1.2 per cent, respectively. After storage of the tubers for 16 weeks at 35° F., the corresponding sloughing losses were 1.2, 0.9, and 0.5 per cent.

It is to be noted that some of our treatments of potatoes were extreme. For instance, a weight loss of 25 per cent during storage would not be experienced in commercial practice. Such treatments are of value, however, in that they serve to magnify small differences which ordinarily would be overlooked and which sometimes lead to an understanding of fundamental problems. In the present case, an understanding of the factors which govern the texture of potatoes is involved.

The hypothesis we have adopted to account for the observed changes in potato tissue texture is based upon differences in the pressure developed within cells by the swelling of starch granules during cooking, and upon differences in the cells' capacity to tolerate pressure. If a cell contains a relatively large quantity of starch, the pressure developed will be great, and the cell will become severely distorted. As a result of this, the intercellular cement may fracture and the cell may separate or slough from the main body of tissue.

In tubers stored at 50° F. and above, sloughing decreases (although specific gravity increases) for the following reasons: (1) tissues of a stored tuber constantly are using up starch in respiration and frequently in sprout formation; (2) meanwhile, the number of cells in the tuber does not change; (3) this means that the amount of starch in each cell constantly decreases; (4) at the same time, the tissues shrink; (5) thus the cells have an increased capacity for expansion at the same time that they contain less starch (swelling agent); (6) in addition, the swelling power of the starch may be diminished slightly by an increased concentration of mineral salts (3); (7) therefore, less pressure is developed within each cell, less distortion of the cell and splitting of the intercellular cement occurs, and the degree of sloughing decreases. Conversely, we would expect the maximum degree of sloughing to occur at or near harvest time when each cell is fully distended and contains its maximum amount of starch.

The sequence of events leading to the decreased sloughing of tubers stored at 35° F. probably is as follows: (1) some of the starch is converted to sugar; (2) this (together with respiration) decreases the amount of starch in each cell; (3) in addition, the presence of sugar diminishes, in a small measure, the capacity of starch to swell (8); (4) accordingly, there is less pressure developed in each cell and less sloughing occurs. If the tubers are transferred to storage at 75° F., sloughing increases owing to the reversal of the same mechanism. The sugar is reconverted to starch more rapidly than it is used in respiration.

The cause for the imperfections in the specific gravity-sloughing relationship is that specific gravity data alone do not reveal the changes in the amount of starch in individual cells. Although the data do reveal fairly accurately the starch content of whole tissues stored at 50° F. or above, a distinction must be made between the per cent starch in a tissue and the relative amount in each cell. For example, before storage a tuber weighing 100 grams may contain 15 per cent, or 15 grams, of starch. After storage the tuber may weigh 80 grams and still may contain 15 per cent of starch as revealed by specific gravity data, but this now is equivalent to only 12 grams of starch. In the latter case, each cell would contain less starch than originally, and less sloughing should be expected. Although the relative amount of starch in each cell cannot be measured directly or conveniently, it apparently is a factor of great importance in determining tissue texture.

Corrective measures for improving the accuracy of the specific gravity grading method appear to be simple. In the present case, at least, it is merely necessary to recognize that the same potatoes may change both in specific gravity and in texture during storage, and that the changes occur in an orderly and predictable fashion. Therefore a number of standard curves may be prepared for converting the specific gravity ratings into terms of texture or of starch content. One curve may be applicable to potatoes stored a definite time at 35° F.; a second curve may apply to dormant tubers stored at 75° F.; and so on. At the present time just one curve is used for tubers which may differ widely in age, in storage history, in shrinkage, and in physiological condition. Some of the disadvantages of doing this have been pointed out in this paper. The currently used curve of von Scheele seems to be most applicable to freshly harvested potatoes and to those stored at 50° F. For other potatoes, restandardization of the curve may result in greater accuracy and in wider use of the specific gravity grading method.

Our hypothesis on texture needs to be tested further. Different varieties of potatoes should be used, and different storage conditions should be studied. When different varieties are compared, their tubers should be identical in age and in storage treatment.

That pectic compounds, especially those composing the intercellular cement, play an important role in determining texture cannot be denied. Without the cement there would be no tissue cohesiveness, no tissue texture. In our concept of textural differences, however, the pectic substances are assigned a passive rather than a causative role, and they are regarded as a relatively constant factor among others which vary. In other words, variations in the starch content of cells have a greater effect upon texture than do variations in the pectic substances. The starch acts principally by developing intracellular pressure which weakens or fractures the pectic cement to varying degrees. If pectic substances were responsible for the changes in texture, one might expect the potato to become increasingly mealy during storage, as do apples. The contrary is true. Furthermore, it is difficult to explain the textural changes which occur in potatoes stored at alternating high and low temperatures in terms of pectin chemistry. The textural changes parallel the changes in starch content of individual cells.

Acknowledgment. We are grateful to Dr. C. O. Willits and Mrs. Mildred Gaspar for the starch and dry matter determinations.

Summary

Certain limitations of the specific gravity method for predetermining the sloughing loss from Irish Cobbler potatoes are revealed. The relationship between specific gravity and sloughing depends partly upon the physiological condition and storage history of the tubers. The extent of sloughing may decrease or increase without any change in specific gravity, or sloughing may even decrease as specific gravity increases. The accuracy of the specific gravity method for indicating starch content also may vary with the storage of tubers. The method is least accurate with tubers stored at a low (35° F.) temperature.

An hypothesis concerning the general nature of potato texture and the mechanism of change in texture is presented. The hypothesis is based upon differences in pressure developed in cells by the swelling of starch during cooking, and upon differences in the capacity of the cells to tolerate pressure. The relative amount of starch in individual cells rather than its concentration in whole tissues determines texture. The amount of starch in a cell may decrease at the same time that its concentration in a tissue increases. For instance, during storage at 75° F., starch in cells is used continuously in respiration and often in sprout formation. This change in starch content is not revealed by specific gravity data because the tuber and cells shrink, become more compact, and may even increase in density. Since the number of cells in a tuber does not change, the amount of starch in each cell decreases, less pressure is developed when the cell is cooked, and a change

toward a waxy texture results. Thus, factors which decrease the amount of starch per cell (*e.g.*, sprout formation, storage at a high (75° F.) or low (35° F.) temperature) hasten the development of a less mealy texture, and factors which retard the decrease (*e.g.*, dormancy, storage at 50° F.) help to maintain the original texture.

Literature Cited

1. Caldwell, J. S., Culpepper, C. W., and Stevenson, F. J. 1944. Suitability for dehydration in white potatoes as determined by the factors of variety, place of production, and stage of maturity. II. Amer. Potato Jour. 21: 217-229.
2. Dunn, L. E., and Nylund, R. E. 1945. The influence of fertilizers on the specific gravity of potatoes grown in Minnesota. Amer. Potato Jour. 22: 275-288.
3. Ripperton, J. C. 1931. Physiochemical properties of edible-canna and potato starches. Hawaii Agr. Exp. Sta., Bull. No. 63.
4. Scheele, C. von, Svensson, G., and Rasmusson, J. 1936. Determination of the dry substance and starch content of potatoes with the aid of specific gravity. Landw. Vers. Sta. 127: 67-96.
5. Smith, Ora. 1950. Growing, shipping, storing, and handling potatoes for the chipping industry. Hints to Potato Growers, Vol. 31, No. 4.
6. Steiner, E. T., and Guthrie, J. D. 1944. Determination of starch in sweet potato products and other plant materials. Ind. Eng. Chem., Anal. Ed. 16: 736-739.
7. Terman, G. L., Goven, M., and Cunningham, C. E. 1950. Effect of storage temperature and size on French fry quality, shrinkage and specific gravity of Maine potatoes. Amer. Potato Jour. 27: 417-424.
8. Whittenberger, R. T., and Nutting, G. C. 1948. Potato-starch gels. Ind. Eng. Chem. 40: 1407-1413.
9. ——— and ———. 1950. Observations on sloughing of potatoes. Food Research 15: 331-339.